Development of Rubber Creping Machine for Improved Profitability in Rubber Production in Agusan del Sur, Philippines

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Development of Rubber Creping Machine for Improved Profitability in Rubber Production in Agusan del Sur, Philippines

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Abstract: *Selling rubber creep sheets is a potential way to increase profitability in rubber farming, especially in Agusan del Sur, one of the top rubber producers in the Philippines. However, creping machines that are suitable for rubber farmers in the region are unavailable. Hence, this study designed a creping machine to increase rubber production profitability. A single factorial experiment in a Completely Randomized Design using three (3) treatments (angular speed) was used to assess the machine's performance. These include creping input capacity, output capacity, efficiency, and thickness of rubber crepe. The results showed the machine's highest output capacity and efficiency of 228.37 kg/hr and 53.70 %, respectively. Among all treatments used, two (2) treatments resulted in a standard crepe rubber thickness of 4.39 mm and 4.92 mm. It is recommended that a 13-rpm speed must be used as an operating speed for the machine to produce an ideal result. The economic analysis of the machine for the said operating condition revealed a benefit-cost ratio of 1.89 and a return on investment of 89.06%. This result indicates that the machine is economically feasible. Hence, utilizing the machine will increase profit for rubber farmers if they sell rubber crepe sheets.*

Keywords: Creping; Angular speed; Rubber; Economic Analysis

1. INTRODUCTION

One of the most profitable crops in the Philippines is Para rubber (*Hevea brasiliensis Muel*) due to its substantial export opportunities. This plant's remarkable adaptability positions it as a valuable global asset with significant potential for sustainable agriculture and economic progress [1]. The country recorded exports totaling $36.4 million in 2016, consisting of latex and crepe sheets exports to Hong Kong, the USA, Malaysia, Taiwan, and Singapore. Para rubber holds immense promise as a dollar-earner crop in the Philippines. This remarkable plant boasts high export potential, making it a desirable commodity in the country's agricultural sector [2]. Additionally, the Para rubber is widely acknowledged as a highly profitable agro-industrial venture in our country, with significant commercial cultivation mainly concentrated in Mindanao.

Dunuwila et al. [3] emphasized the significant contribution of the natural rubber (NR) industry to the economic development of emerging nations, particularly in Asia, where 92% of global NR production is concentrated. In this context, small-scale rubber farmers face inefficient use of materials and high input costs. The process of creping rubber involves labor-intensive tasks such as scraping latex from tree bark, spreading it into thin sheets, and manually creping dried sheets to enhance rubber quality. This laborious step demands considerable time and effort, leading to challenges in achieving high-quality rubber production. As a result, small-scale rubber farmers encounter difficulties in increasing their productivity and profitability.

In the Philippines, rubber farmers earned from selling rubber cup lumps. It is a coagulated material found in the collection cup when the tapper next visits the tree to tap it again. According to the local rubber farmers in Agusan del Sur, selling rubber crepe has never been practiced in the province. However, according to a local buyer of rubber cup lumps, a rubber crepe is three times higher in price than a cup lump because it has already been processed and can already be used to develop rubber-based products. Traditionally, the availability of rubber crepe machines had been limited to large-scale rubber farmers with the financial means to invest in such equipment, as it typically commands a higher price point than cup lumps. However, there are also attempts of developing rubber crepe machine for small-scale rubber farmers as conducted by Hossain et. al [4] who uses a single creping drum for creping latex. Utilizing single creping drum might be suitable for small-scale, however, attaining the desired thickness for the rubber crepe requires high energy input. Another study conducted by Tan et.al [5], examined the effect of highspeed rubber creping machine for increased productivity and reduction of processing time. This machine is advantageous for large rubber industry, however, for Agusan del Sur rubber farmers, investing in such technologies is quite expensive. It is supported by the study conducted by Zakaria et.al [6], who examined numerous creping machine that are appropriate for small-scale rubber farmers. They highlighted the importance of addressing the unique requirements and constraints faced by small-scale producers in order to enable the rubber farmers to participate more easily in the crepe production process.

Therefore, there is a need to develop an affordable rubber creping machine that could be easily operated and constructed using locally accessible materials. Hence, this study was conducted to develop a rubber creping machine. This study also evaluates the performance of the machine in terms of input capacity, output capacity, efficiency and thickness of the rubber. The machine is equipped with easy-to-use controls to help small-scale farmers improve their efficiency, productivity, and profitability in rubber farming. This study is limited to studying the effects of selected factors on the machine's performance. It did not include a comparison with the other literature since its primary aim is to develop a rubber creping machine and assess its economic potential to the rubber farmers.

2. MATERIALS AND METHOD

The researchers employed experimental methodology to conduct this study. This systematic and scientifically rigorous approach allowed the researchers to assess any variations in specific dependent variables in relation to carefully identified independent variables. To evaluate the performance of the proposed machine, the researchers subjected it to a single-factor, three-level treatment analysis. This thorough methodology offered valuable perspectives on its capabilities and functionality.

2.1 Machine Design

The rubber creping machine shown in Figure 1 is equipped with specialized rollers that can evenly spread and thin the rubber to achieve the desired thickness. The result was a pale crepe that had excellent elasticity and abrasion resistance, making it ideal for applications in industries such as automotive, footwear, and construction. The machine comprised a creping unit with two pairs of rotating rollers positioned horizontally, rotating in opposite directions; the first pair of rollers was used for cleaning and had a diagonal cross-section designed groove in the outside surface of the roller, which was 14 inches long, and 4.5 diameter. The second one had a 14-inch and a 4.5-inch diameter below, which was used for finishing; it was designed to be a smooth roller, and the other roller had the same length, which was 14 inches long with a diameter of 2 3/8" positioned in the middle at the back of the hopper. The purpose of the roller which had 2 3/8" diameter was to block the rubber coagula from rolling at the back of the hopper and to allow the creping to move freely. The above roller clearance was set to be 4mm, and the below roller clearance was set to 3mm. The rollers were made from steel and had to be precisely machined to ensure uniformity in the creping process. The one hp motor drove the rollers and controlled their speed, and the control system allowed operators to adjust the machine's settings to achieve the desired level of creping. The frame was constructed using a 3-length (¼ x 2) angle bar of 80 cm height. The machine consisted of a 10 ft chain and sprockets that drove the main shaft.

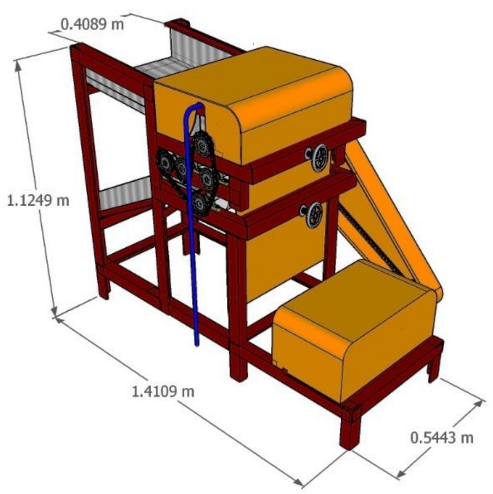

Fig. 1. Working Design of Rubber Creping Machine

2.2 Sample Preparation

The rubber latex was purchased and collected directly from rubber farmers at Rosario, Agusan del Sur rubber plantation. The rubber latex was in liquid form, and then it was filtered in a coagulant bath that had been prepared to achieve clean samples. Latex, which had been filtered, was mixed with formic acid. After that, it was put on a molder and weighed by measuring its molder using a weighing scale for coagulation, 2 kg/molder [7]. After coagulation, it was ready for the operation on the machine.

2.3 Experimental Design

The study used a single factorial in Completely Randomized Design (CRD) to evaluate the performance of the machine with respect to the angular speed of the roller of the machine. Three treatments with three replications were used during the performance evaluation. The summary of the treatments used is presented in Table 1. A two (2) kg rubber coagula was used during each run.

Table 1. Summary of Treatments

Treatment	Level
T1	17.14 rpm
T2	13.30 rpm
T3	12.00 rpm

2.4 Data Gathered

The following data were gathered during the conduct of the experiment:

1. Average thickness of the rubber coagula before creping.
2. Average thickness of the rubber crepe.
3. Weight of the rubber crepe after creping.
4. Total operating time for each run.

2.5 Performance Evaluation Parameters

The following parameters were used to evaluate the performance of the machine for both technical and financial performance.

2.5.1 Creping Input Capacity

The creping input capacity was measured by weighing the latex coagula loaded into the machine at a specific time. The total operating time began when the latex coagula was fed into the creping machine until it was creped into 3-5mm. It can be calculated using equation 1.

$$C_c = \frac{W_i}{T_o} \qquad (1)$$

where: C_c= Creping Input Capacity, kg/hr
W_i= Total weight of crepe latex, kg
T_o= Total operating time, hr

2.5.2 Creping Output Capacity

The creping output capacity was measured by weighing the output rubber crepe into the machine's operating time. The total operation time began when the latex coagula was fed into the creping machine until it was totally creped. The creping output capacity is expressed mathematically using Equation 2.

$$C_o = \frac{W_o}{T_o} \quad (2)$$

where: C_o= Creping Input Capacity, kg/hr
W_o= Total weight of crepe latex, kg
T_o= Total operating time, hr

2.5.3 Creping Efficiency

Creping efficiency was determined by calculating the percentage error of attaining the desired thickness (3 mm) to the actual thickness attained in every treatment. The percentage error calculated is subtracted to 100% to achieve the machine's creping efficiency. It is expressed mathematically using Equation 3.

$$C_{eff} = 100 - \left|\frac{T_M - T_P}{T_P}\right| \quad (3)$$

where: C_{eff} = Creping Efficiency, %
T_M = Measured Thickness, mm
T_P = Predicted Thickness, mm

2.5.4 Rubber Crepe Thickness

A caliper was used to measure the thickness of the rubber crepe. The researcher used several point areas in the sample to measure the thickness, and then the average thickness was measured using the six measured thicknesses in the sample.

2.6 Statistical Analysis

All the data was gathered and tabulated following a Completely Randomized Design (CRD) layout. The significance of every treatment means was analyzed using Analysis of Variance (ANOVA). A post-hoc analysis using Duncan's Multiple Range Test (DMRT) was used to test which treatment means is significantly different from others.

2.7 Economic Analysis

For the economic analysis of developed rubber creping machines, the Return of Investment (ROI), and Benefit-Cost Ratio (BCR) were used as an indicator of economic feasibility [8].

2.7.1 Net Present Value (NPV)

Net present value (NPV) is used to evaluate the present value of a series of future cash flows to the investment's initial cost. The product is profitable at the rate of interest set if the NPV is positive. It can be calculated or mathematically expressed by this equation.

$$\text{NPV} = -C_o + \frac{C_1}{1+r} + \frac{C_2}{(1+r)^2} + \cdots + \frac{C_n}{(1+r)^T} \quad (4)$$

Where:
C_o = intial investment
C = cash flow
R = interest rate
T = time

2.7.2 Benefit-Cost Ratio (BCR)

The cost-benefit ratio evaluates a project's net benefit in relation to its net cost. A ratio greater than 1 indicates that the project's benefits outweigh its costs, whereas a ratio less than 1 indicates that the costs outweigh the benefits. It can be expressed mathematically by this equation.

$$\text{BCR} = \frac{\text{PV of benefit expected from the project}}{\text{PV of the cost of the project}} \quad (5)$$

2.7.3 Return of Investment (ROI)

The time it takes for an investment to recover from the related cash flows. It can be calculated using this equation.

$$ROI = \left(\frac{TI - TC}{TC}\right)100 \quad (6)$$

2.7.4 Payback Period

The time it takes for an investment to recover from the related cash flows. It can be calculated using this equation.

$$\text{Payback Period} = \frac{\text{Cost of project Investment}}{\text{Annaul Cash Inflows}} \quad (7)$$

3. RESULTS AND DISCUSSIONS

3.1 Machine Description

The machine (Fig.2) was designed and fabricated to produce pale crepe rubber; a type of high-quality rubber widely used in various applications. In the first design, the machine is composed of a pulley and gear instead of a chain and sprockets for its power transmission. The researcher replaced it with chain because it is more suitable mechanism that are much stronger and more durable and to prevent belt slippage from the pulley. The use of sprocket instead of gears was preferred because it is more cost effective. The actual developed machine comprised a creping unit with two pairs of rotating rollers positioned horizontally, rotating in opposite directions; the first pair of rollers was used for cleaning and had a diagonal cross section designed groove in the outside surface of the roller which was 14 inches long, and 4.5 inches diameter. The second one had a 14-inch and a 4.5-inch diameter below, which was used for finishing; it was designed to be a smooth roller, and the other roller had the same length which was 14 inches long with a diameter of 2 3/8 inches positioned in the middle at the back of the hopper. The purpose of the 2 3/8-inch diameter roller was to block the rubber coagula from rolling at the back of the hopper and to allow the creping to move freely. The above roller clearance was set to be 4mm, and the below roller clearance was set to 3mm. The rollers were made from steel and had to be precisely machined to ensure uniformity in the creping process. The upper hopper length is 32 cm and 36 cm below. The 1 hp motor drove the rollers and controlled their speed, and the control system allowed operators to adjust the machine's settings to achieve the desired level of creping.

Fig. 2. Actual Design of the Creping Machine

3.2 Creping Input Capacity

The performance of the rubber creping machine in processing rubber latex into rubber crepe was determined in relation to the number of teeth of the sprocket corresponding to the angular speed of the roller press. It was determined by dividing the input rubber latex's weight by the creping process's total operating time expressed in kilogram per hour (kg/hr).

The machine's creping input capacity, as presented in Table 3, were 417.89 kg/hr, 342.02 kg/hr, and 265.25 kg/hr, for T1, T2, and T3, respectively. Based on the results presented in the same table, there was a linear correlation between the diameter corresponding to the angular speed of the roller press and the input capacity, in which the increasing speed of the roller press increased the input creping capacity of the machine. This result was primarily because higher speed will result in a much shorter operating time for the rubber to be creped.

Moreover, based on the summary for the Analysis of Variance (ANOVA) conducted and presented in Table 2, there was a significant difference between the selected treatments (angular speed) at $\alpha=0.05$ in relation to the input capacity of the rubber creping machine. A post-hoc analysis using Duncan's Multiple Range Test (DMRT), as shown in Table 3, was conducted to determine which selected treatments differed significantly from the others. The result presented in Table shows that there was no significant difference between T1 (17.14 rpm) over T2 (13.3 rpm) and T2 (13.3 rpm) over T3 (12 rpm). However, the result shows a significant difference between the treatment means of T1 and T3, in which T1 resulted in a much higher input creping capacity over T3. A higher speed will result in a much higher input creping capacity. Furthermore, the coefficient of regression (R^2), as shown in Table 2 for the angular speed in relation to the input capacity, is equal to 74.4%, which means that the angular speed can explain 74.4% of the variability of the input creping capacity as a factor. Other factors should be included in future analyses to increase R^2 in relation to the input creping capacity and provide a more robust analysis of the said response.

Table 2. Analysis of Variance for Creping Input Capacity

Source of variation	df	SS	MS	F-Value
Treatment	2	34,951.912	17475.956	8.735*
Error	6	12,003.835	2000.639	
Total	8	46,955.747		

** highly significant $R^2 = 74.4\%$

Table 3. Post-Hoc Analysis for Creping Input Capacity

Treatment	Means
T1	417.89[a]
T2	342.02[ab]
T3	263.74[b]

**All means followed by the same letter are not significantly different at 0.05 level (DMRT)

3.3 Creping Output Capacity

The performance of the rubber creping machine in producing rubber crepe was determined in relation to the sprockets' different number of teeth corresponding to the angular speed of the roller press as an independent variable. It was determined by dividing the weight of the rubber crepe by the total operating time to process and flatten the crepe expressed in kilogram per hour (kg/hr).

The output capacity per treatment is presented in Table 5. It shows that the average output capacity was 228.37 kg/hr, 210.09 kg/hr, and 158.40 kg/hr for T1, T2, and T3, respectively. The highest output creping capacity attained by T1 was primarily due to the short operating time due to its high speed. The Summary for the Analysis of Variance (ANOVA) presented in Table 4 was conducted to test the significant differences between treatments. It showed a highly significant difference between each angular speed used in the study.

Using the Multiple Duncan Range Test (DMRT) presented in Table 4, it was found that there was a highly significant difference between T1 and T2 over T3. This means that the higher the speed, the higher the output capacity can be attained by the creping machine. The high coefficient of regression (R^2) shown in the same Table indicates that the variability of the output capacity can be explained by 82.4% of angular speed as a factor. However, this result does not automatically implicate that a higher speed must be used to attain the desired rubber crepe output since the rubber's thickness must also be considered in the selection.

Table 4. Analysis of Variance for Creping Output Capacity

Source of variation	df	SS	MS	F-Value
Treatment	2	7,901.647	3,950.823	14.088**
Error	6	1,682.648	280.441	
Total	8	9,584.295		

**significant $R^2 = 0.824$

Table 5. Post-Hoc Analysis for Creping Output Capacity

Treatment	Means
T1	228.37[a]
T2	210.09[a]
T3	158.40[b]

**All means followed by the same letter are not significantly different at 0.05 level (DMRT)

3.4 Creping Efficiency

The rubber creping machine's efficiency in the rubber crepe production was tested using the sprockets' different number of teeth corresponding to the angular speed of the roller press as an independent variable. It was determined by calculating the percentage error of attaining the desired thickness to the actual thickness attained in every treatment. The percentage error calculated is subtracted to 100% to achieve the machine's efficiency.

The creping efficiency of the machine as presented in Table 6 was 25.93%, 36.11%, and 53.70% for T1, T2, and T3, respectively. Based on the results, a lower speed, which was T3 (12 rpm) roller press resulted in the highest creping efficiency. It was observed during the machine evaluation that a slower speed of the roller press resulted in a much longer retention time of the rubber latex into the creping section. This means that the longer it stays in the creping unit, the more the rubber latex is pressed, thus the closer it gets to the desired thickness of the rubber crepe. The high speed of the roller presses results in much lower efficiency because the retention time of the rubber latex in the creping unit is shorter than the other treatments.

However, based on the Analysis of Variance (ANOVA) conducted and presented in Table 7, there was no significant difference between treatments, which means that there's no significant effect caused by the varying level of speed to the creping efficiency. This was because the set clearance combination of 4mm and 3mm will result in an almost equal thickness of the rubber crepe sample for all treatments regardless of the speed to use, which resulted in no significant difference for all treatment means. It can be supported by a lower R^2, as shown in Table 7, equal to 46.4.2%, which means that only 46.4% of the variability of the crepe efficiency can be explained by speed as its independent factor. Hence, using speed alone to evaluate creping efficiency was insufficient to describe the variability of the said response. This result means other variables must be included in the machine performance evaluation for a better model analysis.

Table 6. Summary of Creping Efficiency per Treatment

Treatment	Mean
T1	25.93
T2	36.11
T3	53.70

Table 7. Analysis of Variance for Creping Efficiency

Source of Variation	df	SS	MS	F-value
Treatment	2	1,184.973	592.486	2.598^{ns}
Error	6	1,368.428	228.071	
Total	8	2,553.401		

^{ns} not significant $R^2 = 0.464$

3.5 Rubber Thickness

The machine's performance in attaining the desired rubber crepe thickness was tested using the sprockets' different number of teeth corresponding to the angular speed of the roller press as an independent variable. The result of rubber crepe thickness was shown in Table 8, which shows that the creping thickness ranges from 4.39 mm to 5.22 mm. According to the Indonesian National Standard Rubber, the standard crepe thickness ranges from 3-5 mm. Two (T2 and T3) treatments which were the 13.3 rpm (36 teeth) and 12 rpm (40 teeth) qualify the standard rubber crepe thickness. During the machine performance evaluation, the researcher observed that the standard thickness can be achieved easily at a slower angular speed. This result was primarily because of the retention time of the rubber coagula while being crepe by the roller presser. The lower the speed, the longer it takes to finish the creping process. Thus, more time rubber coagula be pressed in the pressing unit, unlike at higher speeds in which the creping process was much faster, hence, the shorter retention time for the rubber coagula.

However, based on the Analysis of Variance (ANOVA) conducted and presented in Table 9, there was no significant difference, which means that regardless of speed, it will result in the same thickness of rubber crepe. The clearance of the roller press was set to 3 mm; however, based on the results, no treatment results in a 3mm rubber crepe. This was because of the elastic property of rubber crepe, which was not included as a variable in the evaluation. When the rubber coagula were forced to pass the 3 mm clearance, it can easily pass. However, the elastic property of the rubber crepe expands as it goes out to the machine's outlet. This result was supported by a lower R^2 of 46.3% as shown in Table 9, which indicates that other variables must be included in the experiment to explain the variability of the crepe thickness. This might include the number of passes of the rubber crepe.

Table 8. Summary of Rubber Thickness per Treatment

Treatment	Mean
T1	5.22
T2	4.92
T3	4.39

Table 9. Analysis of Variance for Rubber Thickness

Source of variation	df	SS	MS	F-value
Treatment	2	1.066	0.533	2.591^{ns}
Error	6	1.234	0.206	
Total	8	2.300		

3.6 Economic Analysis

Economic analysis for using the developed rubber creping machine was conducted to test if the machine will positively impact rubber farmers in Agusan del Sur, Philippines. For analysis, the average volume produced per hectare was calculated based on the Philippine Rubber Industry Roadmap 2022-2028 [9]. It is assumed that rubber farmers in the Philippines hold an average of 3 hectares (Ha), which produces a Natural Rubber (NR) of approximately 800 kg/ha-year. The general assumption for the economic analysis is presented in Table 11.

The summary of the economic analysis is presented in Table 10. The analysis shows that the Net Present Value (NPV) from the developed machine's economic benefit is PHP 206, 069.63; a positive NPV indicates that using the machine is economically feasible. The rate of investment (ROI) is 89.06%, which is higher than the discount rate used in the analysis, which means it is economically feasible. The benefit-cost ratio (BCR) is 1.89, which means that every peso of investment will give a 0.89 peso return of benefits to the rubber farmer. The rubber creping machine's investment can be recovered within two (2) years of operation. In summary of the results, using the machine in rubber farming to sell rubber crepe is economically feasible.

Table 10. Summary of Economic Analysis

Economic Indicator	Value
Net Present Value (NPV)	PHP 206,069.63
Rate of Investment (ROI)	89.06%
Benefit-Cost Ratio (BCR)	1.89
Payback Period	2 years

Table 11. Economic Analysis Major Assumptions

General Assumptions	Value
Machine Output Capacity	210.09, kg/hr
Average Recovery After Drying	75%
Average Production of Natural Rubber (NR) per year	800 kg/ha-year

General Assumptions	Value
Average Land Area per Rubber Farmer	3-Ha
Selling Price of Rubber Crepe	PHP 120/kg
Discount Rate	30%
Annual Benefits	**PHP 216,000.00**
Fixed Cost	
Machine	PHP 45,000.00
Depreciation	PHP 9,000.00
Tax and Insurance (12% from Machine Cost)	PHP 6,000.00
Variable Cost	
Laborer (one operator @ 350/day) with a 10% increase annually	PHP 91,000.00
Repair and Maintenance (5% increase annually as machine ages)	PHP 4,000.00
Electricity for 1hp electric motor (@18php/kWH) (2% increase annually for the rate of electricity)	PHP 205.63
Total Annual Cost (Year 1)	**PHP 160,205.63**

4. CONCLUSIONS

The rubber creping machine developed in this study can process rubber latex into rubber crepe. Based on the results, the roller speed affects the machine's capacity. The higher speed will eventually result in a higher capacity. However, the higher the speed, the shorter the retention time of the rubber latex inside the rubber roller, which affects the final thickness of the rubber crepe. It shows that attaining the standard thickness requires a slower speed. Based on the economic analysis, it is concluded that utilizing the machine for rubber crepe production will positively impact the rubber farmers in Agusan del Sur, Philippines.

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